THESIS - **BACHELOR'S DEGREE PROGRAMME**
TECHNOLOGY, COMMUNICATION AND TRANSPORT

NEW LASER CUTTING MACHINE SELECTION PROJECT

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THESIS
Abstract

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Abstract

This thesis is part of AFT´s laser cutting machine investment project. The client is Aikawa Fiber Technologies, Varkaus. The thesis provides client information on laser cutting, discusses differences between the CO2 and Fiber laser, the suitability of these lasers as a new cutter and a recommendation. The goal of the thesis was to work with the development team and help to determine from different options a suitable laser cutter for AFT´s macroflow2 production.

In the theory part of the thesis, laser theory and laser cutting theory is explained. Also, the comparison between CO2 and Fiber-laser is gone through, in perspective of AFT´s needs.

In the practical part, the test cut results and data gathered through the project are reported. All the results cannot be covered in detail due to confidential information. The results are used to determine the suitability of tested machines for Macroflow2 production and then compiled in an official recommendation to AFT´s chain of together with the development team.

Keywords
LASER, AFT, MF2, TEM, Feedrate, KERF, MPa, EN.14404, EN.1.4301, CO2, Fiber, Nd-YAG, Disc, mm, NC, CNC, kW

CONTENTS

1 CASE INTRODUCTION

In this thesis technical background research, comparison and testing of different laser cutters are used to determine and propose the best possible option for Aikawa Fiber Technologies Varkaus. First it is necessary to go through the physics behind the formation of laser beam, laser light, laser cutting and then comparison between lasers is made. Based on this the idea is to find best possible solution for AFT.

1.1 NEW LASER SLECTION PROJECT – BACKGROUND AND GOAL

AFT uses Trumpf´s 7040 CO2 laser as their current and only laser cutter. Laser is used to manufacture support rings for Macroflow2 screen cylinders and materials cut with the machine are corrosion resistant stainless steels EN.14404 and EN.1.4301. The assist gas used is nitrogen. These support rings can have a maximum diameter of 1699 mm and thickness of 4 mm or 6 mm. The cylinders are built out of top, bottom and support rings and attached together by profile wires. To avoid weld beads AFT cuts these rings in shape for the profiles wires and uses heat shrinkage to assemble the final cylinder.

Now the cutter has been used for more than 55 000 hours and it is 10 years old. The cutter has started to lose its accuracy and is expensive and unreliable in production. AFT needs accurate, reliable, and repetitive machine fitting their production. Thesis goal is to provide technical background of new cutter options and new resonator options. This also includes working as a part of development team and creating official reports of test cuts done by providers.

1.2 AFT AS AN COMPANY

AFT is an abbreviation of Aikawa Fiber Technologies. The company was established in 1903 in Quebec, Canada and worked under the name of Union Screen Plate. In 1924, a Japanese company Aikawa bought the company, renaming the whole company Aikawa Fiber Technologies, AFT globally. In years 1945, 2001 and 2013 AFT branched to three countries Finland, South Korea, and China. Today AFT´s main field is in pulp and paper industry machinery and serving different customers on food and mineral industry as well.

AFT has five different manufacturing facilities and three service hubs in the USA, Brazil, and Finland. These manufacturing facilities are placed in:

- Sherbrooke, Quebec, Canada
- Varkaus, Finland
- Incheon, South Korea
- Jiaxing, China
- Fujieda-City, Shizuoka, Japan

All the facilities have similar production capabilities, but certain products are divided to specific plants.
AFT´s focus is on fiber separation. From chemical-, mechanical, recycled fibers and fiber refining to food screening and separation. This includes also testing- and laboratory facilities. Manufacturing includes OEM products and customer specific spare parts, divided by different manufacturing locations. These production branches are divided in four different product categories:

- Aikawa Technologies
- Finebar Refining
- Max Screening
- POM Approach Systems
- Service for P&P industry

Aikawa Technologies includes Refining equipment, Recycling equipment, Headbox screens, Coarse reject sorters and Coarse recycled fiber screen and Laboratory equipment. Headbox screens include custom-made outflow- and inflow screens, cylinders, and rotors for paper industries. Reject sorters are for recycled fiber applications. Laboratory equipment includes pulpers, screens and refiners for pilot plants, which are used for commercial usage. (Aft-global 2020)

Finebar refining contains ultra-low intensity refining plates, which are customizable for the mill's specific needs. These consist of mini-segment refiner plates, standard disc refiner plates and conical refiner fillings. MS or Mini-Segment refiner plates are replaceable surface plates for the refiner disc, they are energy-efficient, cost reducing and long lasting. MS weigh only a fraction of the plate and are easy to install with bolts. Standard refiner plates are older product serving same purpose. Manufactured with laser cutting and precise assembling has benefits in refining compared to traditionally cast or welded plate. (Aft-global 2020)

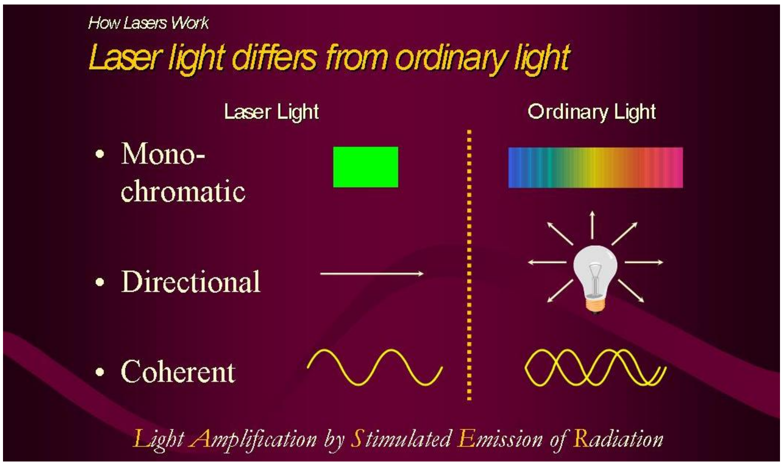
Max screening contains cylinders, rotors and screens used for fiber technologies. AFT divides cylinders to different categories from wedge wire-, electro beam drilled, normal drilled and macroflow cylinders. Rotor models are divided by different refining elements and foils. (Aft-global 2020)

2 LASER PRINCIPLES AND RISKS IN OPERATION

In this chapter, the meaning of the word laser is explained in more detail and how it works. It is also explained what safety aspects need to be followed when using a Laser and possible injuries which can happen.

2.1 WHAT IS LASER?

"The word LASER is an acronym for Light Amplification by Stimulated Emission of Radiation "(Lawrence Livermore National Laboratory, publish date unknown). Laser provokes atoms when connected to power source, after provoking electrons start rotating continuously on atoms nucleus. The electrons create more potential energy the further from the nucleus. This takes only fraction of second to happen and after electrons return to original places, energy releases photons and narrow beam is formed. (Basic laser theory 2019) Laser itself is a device, which provides stream of coherent light. The light waves produced have same wavelength, resonate on same frequency and are one colored. This differs from a regular light where it radiates all around the premise of device, emitting in different colors, as seen in picture 1.



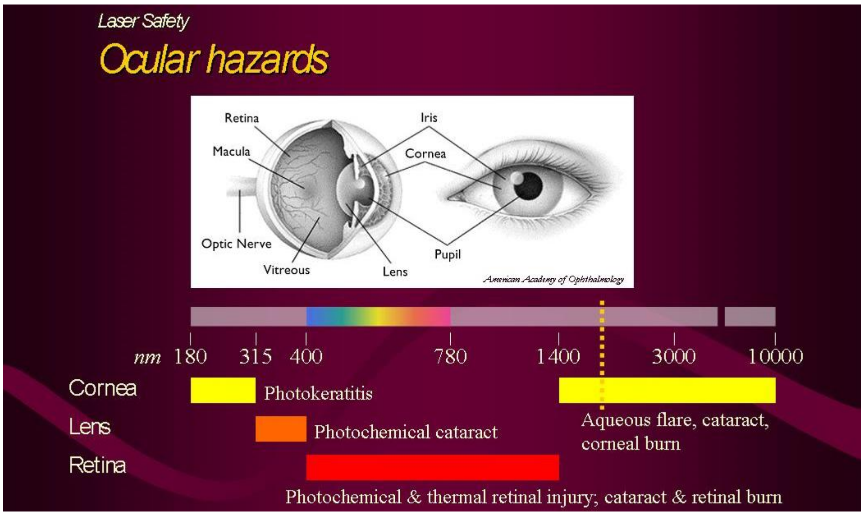
PICTURE 1. Laser light theory (How lasers work 1999-2012)

2.2 WORK SAFETY AND PRECAUTIONS

Because laser is missing the dispersion rate of regular light, it can be projected as a beam over distances while maintaining nearly all its power output (Laser cutting theory 2019, 1-10). For this reason, work safety and risk must be known when operating a laser. The space where laser is must have restricted access or safety perimeter, warning signs must be near the space or the entrances leading operation space and protective eyewear with appropriate optical density rating must be used to avoid direct exposure and specular reflection. (How lasers work 1999-2012)

2.3 SAFETY RISKS OF LASER

Laser´s properties make it a precise tool, which can be hazardous to human body. Laser light exposure to skin can cause burns, pigment darkening, or increase on pigmentation. When dealing with industrial lasers cuts are a possibility as well. Ocular hazard is more severe which can cause harm to eye or loss of eyesight. (Maltais 2020). In picture 2 it is seen how difference in laser´s wavelength can cause harm to human eye.



PICTURE 2. Possible ocular hazards when working with laser (How lasers work 1999-2012)

3 LASER CUTTING

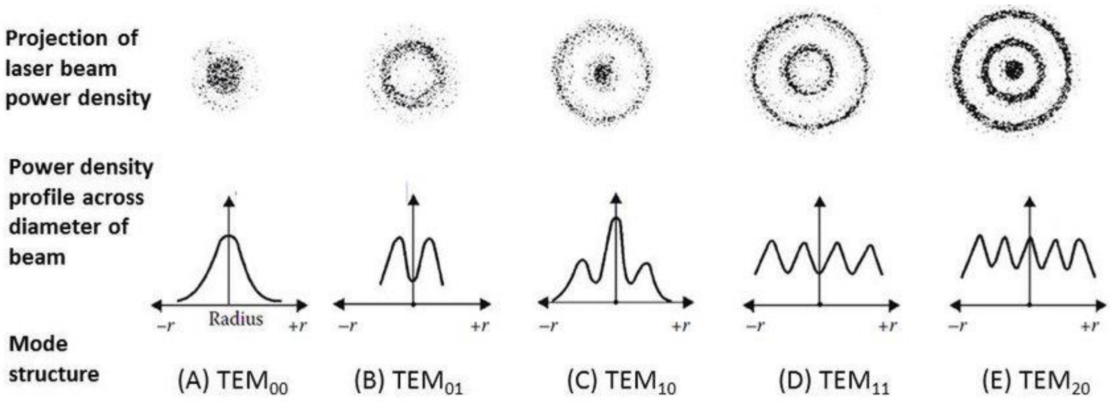
Laser cutting is a complex process of how material is cut with the best possible quality and as fast as possible. The theory and cutting aspects are explained further in this chapter. In addition, it is explained why laser cutting is a good option for increasing productivity and lowering production lead-time.

3.1 THEORY

In laser cutting material is exposed to intense heat energy developed by beam of light. When the heat input is greater than material´s reflecting-, conducting- or disperse capability, the input heat is capable to vaporize or melt a hole on the material. This combined with linear movement provides a cutting action. To have control over the beam´s cutting quality, performance characteristics that affect power density need to be adjusted for every cut. These characteristics need more detailed explaining for understanding the whole cutting process. (Laser cutting theory 2019, 1-10).

3.1.1 MODE

A cross-section of laser beam profile is called a mode or TEM (Transverse Electromagnetic Mode). The mode influences how great power density and spot size are, in other words what the final size of the laser beam will be. When the mode nears Gaussian distribution, laser can be focused on minimum spot size and have greatest power density for cutting in theory. In picture 5 there are different modes and density this creates. It is mandatory that the laser should be operating in the TEM00 mode; it has the lowest threshold, smallest beam waist and divergence. Still different modes are used in various applications. (TT53 Publish date unknown, 3-9).



PICTURE 3. Power density differences between TEM modes. (ResearchGate 2018).

3.1.2 POWER OUTPUT

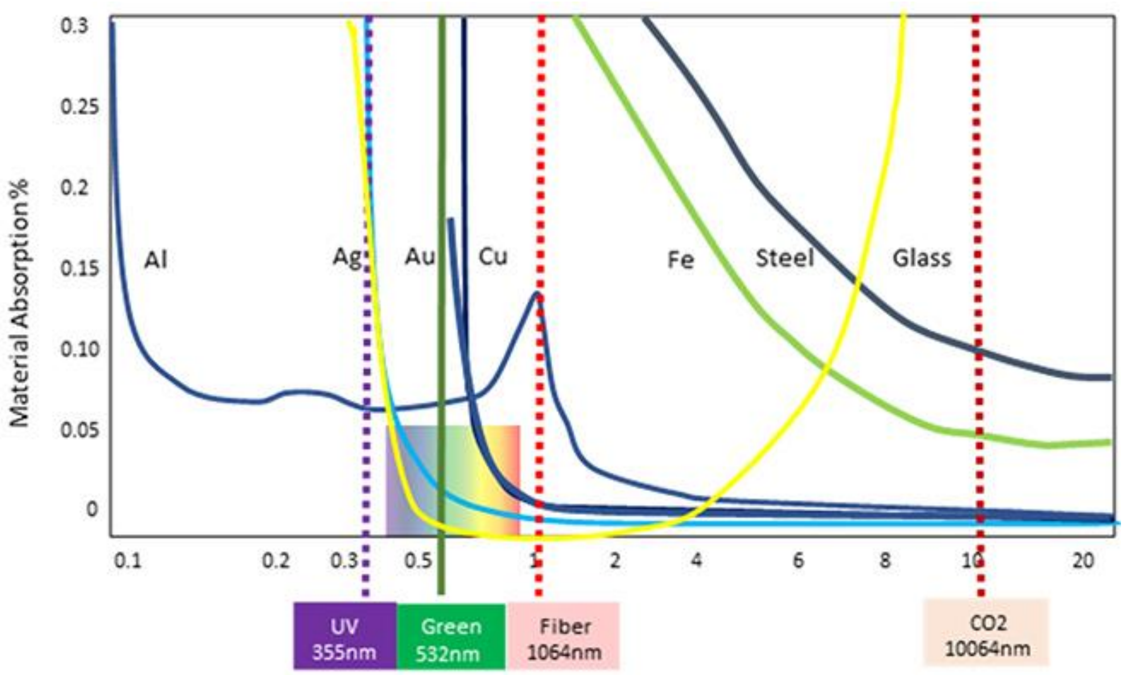
The power output of a laser is measured in watts. Usually in cutting 80-90% of this output is used, leaving 10-20% of maximum power for gaining a clean cut. Industrial laser cutting is a thermal process, which leads to a large amount of power consumed to produce enough heat to vaporize and melt the material. More power means faster processing speed and possibility to cut thicker material in cost off reduced cut quality. (Laser cutting theory 2019, 1-10).

3.1.3 STABILITY

Stability has three different stages in laser cutting. Power stability: maintaining unwavering output of energy. Mode stability: keeping consistent beam quality during a cut. Pointing stability: fixed energy concentration to certain point. During cutting, slightest instability in any of the mentioned will result a noticeable change in power density, leading to possible failure in material penetration and clean cut. (Laser cutting theory 2019, 1-10).

3.1.4 POLARISATION AND ABSORPTION

Polarization is material processing laser characteristic that is apparent in metal or ceramic cutting. Due to its unpredictability effect to absorption of the beam´s energy, lasers are equipped with optical lens options, which fix the polarization direction to be as same as the cutting action. (Laser cutting theory 2019, 1-10). Different materials absorb and reflect different wavelengths, meaning not all lasers are suitable for cutting the same materials. Highly reflective aluminum can be cut with Fiber laser as its wavelength is near 1060nm, as the CO2 wavelength is near 10060 nm this makes it nearly impossible to penetrate material with good surface quality.



PICTURE 4. Materials absorption rate in % depending on resonator, wavelength, and material. (Controllaser publish date unknown)

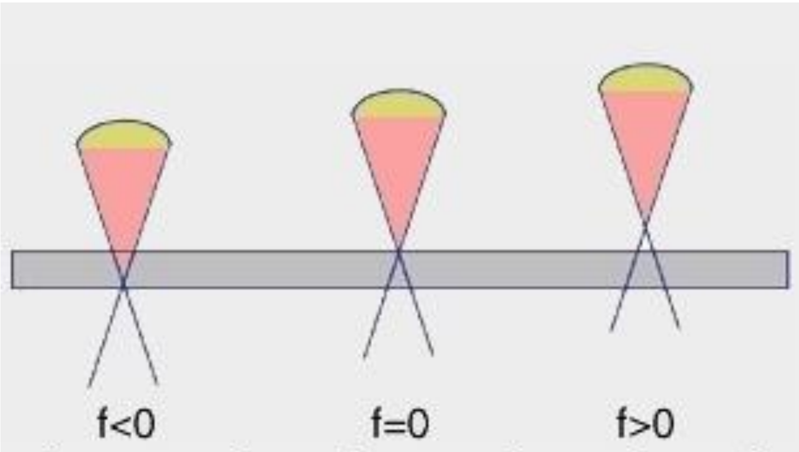
3.1.5 CUTTING SPEED

Laser´s cutting speed is measured with feedrate, which means material removing rate in a linear unit per minute in millimeters or meters per minute. (Multicam 2018) Feedrate is adjusted with laser´s additional power, mode, smaller focus point, lower material density or material thickness. If the feedrate is too high, the cut will not penetrate the material or excessive heat will damage the materials surface. Most of the NC-systems can automatically change the cutting power and the feedrate before or during the cut. (Laser cutting theory 2019, 1-10).

3.1.6 FOCUSING LENS, FOCAL POINT AND FOCAL HEIGHT

Focusing lens concentrates the beam to the materials surface. The focal height of focusing lens is the distance from the nozzle to focal point. Focal height differs between 5-25 centimeters. Short focal heights have greater power densities but are limited to short range of application, therefore being better for thin materials and higher speed operations. Longer focal heights have lower power densities but can maintain densities in larger range, being great for thick materials. Materials reflectivity effects focal height. (Laser cutting theory 2019, 1-10).

The focal point or focus point is where the laser beam´s diameter is smallest and power density largest. The point is normally slightly below the material´s surface for clean cutting, but this is also dependent on the material. For carbon-steel, the ideal focal point is on the surface of the work piece´s material, whereas the focus point of stainless steels is below the work piece. (Laser cutting theory 2019, 1-10).



PICTURE 5. Focal point examples (Idacontrol publish date unknown)

3.1.7 ASSIST GAS

Assist- or auxiliary gas protects focusing lens, cools the surface and helps in material removal from KERF during cutting. These gasses are normally oxygen or nitrogen and they are brought to the cut coaxially.

Oxygen removes the excess material, cleans the cut zone while cooling the material for burns and works to promote exothermic reaction. The purity requirement for oxygen is 99.95% and it´s mainly used to cut carbon steel. The enhanced energy intensity from oxygen can improve cutting speed by 25%-40%.

Nitrogen is used to prevent oxidation what makes it better for stainless steel, brass, and aluminum alloys. For nitrogen purity requirement is 99.999%. Impurities in the gas can cause damage to lens, fluctuations to cutting power and inconsistencies to cut surface. (Machinemfg 2018)

Delivery pressure of gasses helps prevention of slag or dross on cut edge and protecting focusing lens. Oxygen´s pressure varies between of 0.3-1 Mpa and Nitrogen´s largely from 1,5 Mpa to 2 Mpa or higher depending on material thickness. When changing the material to thicker, pressure is reduced, or process speed lowered normally. (Laser cutting theory 2019, 1-10).

3.2 DIFFERENT LASER CUTTING PROCESSES

As mentioned in the theory part, in laser cutting material is exposed for intense heat energy developed by beam of light. This beam can either vaporize or melt the material to make a cut or hole. These processes are similar but serve different purpose depending example on material used to cut or application of cutting.

3.2.1 VAPORIZATION CUTTING

When material is exposed to large amount of heat the surface temperature of the material reaches its boiling point so fast it avoids melting by heat conduction. This leads the vaporizing material into steam, or it is blown away by auxiliary cutting gas. This requires high laser power. Vaporization cutting is only used in application where there is no need to avoid removal of molten material. (MachineMfg 2019).

3.2.2 MELTING CUTTING – WITH OXYGEN

Oxygen is considered as standard assist gas for mild and carbon steels where oxidation of surface is needed. When cutting the material is burned, vaporised, and liquid material is then removed from the cut by sheer force of oxygens pressure. At the same time, oxygen reacts with metal creating additional heat supporting the cut process and oxidation layer on materials surface. (Linde-gas 2021)

3.2.3 MELTING CUTTING – WITHOUT OXYGEN

Sometimes oxygen cannot be used due to oxidation layer it will create to cut, for example when cutting corrosion resistant stainless steel. For these cases, inert gasses are used for cutting such as nitrogen or argon. These gasses do not react with molten metal; they only prevent oxidation or discolouring of the material and blow the molten material out of KERF. For this reason, bigger laser power and auxiliary gas pressure is needed. (Linde-gas 2021)

3.3 BENEFITS AND DRAWBACKS OF LASER CUTTING

Benefits of laser cutting include increased productivity by decreasing process time, decreased manual labor and waste of excess material. Laser cutting is flexible for most plate thicknesses, sizes, and more accurate compared to other heat cutting applications. The cut accuracy is +- 0.1 mm normally before any material treatment. Almost fully automated process has higher cutting speed than other mechanical cutting processes. Experienced operator can operate laser with minimal man labor. Due to laser cutting using only the beam to cut, "contactless" cutting doesn´t wear parts by friction. It only requires minimal wear part changes and maintenance 1-3 times a year ideally. Standard laser-cutter´s lifetime expectancy is between 5-10 years if maintained properly, when comparing to AFT´s current laser this does not apply because the machine is custom build. Versatility is also one of the strong points of laser cutting. Lasers are designed to cut materials varying from metals, acrylics, wood etc. (Velling 2020)

Drawbacks of laser cutting mainly revolve around how expensive it is. Investment of getting laser-cutter can cost 20 000 – 1 000 000 euros, depending on manufacturing demand and industry. Running cost includes laser- or assist gasses and maintenance costs, depending on laser resonator option and power output. The larger the machine the more expensive it is to maintain. In performance standards laser cutting struggles when cutting material thicker than 15-20 mm or if the machine is capable to cut more accuracy will decrease. As said before experienced operator can decrease man labor and increase process time, but this needs knowledge and right layout to produce products fast. Safety risks are also always present when working with high heat- and power density. (Velling 2020)

4 LASER CUTTER OPTIONS

For industrial laser cutting there are five main laser types which are commonly used, all having similar components but different resonator units. These laser types are Nd-YAG-laser, Diode laser, Disc laser, CO2 laser, and Fiber laser. Of these options, CO2 and Fiber laser are most used and the ones AFT is considering. In this chapter the main components of laser cutter are explained and how CO2 and Fiber laser work.

4.1 LASER CUTTING MACHINE COMPONENTS

Laser cutting machines have same basic components, the biggest difference comes from the resonator option chosen. The Biggest individual parts are the machine´s body, cutting platform and operating table. Cutting platform or table moves in and out of the cutter with servo- and stepper motors or gear racks and pinions. The Table can be moved on x, y, and z-axis. (MachineMfg 2018)

Laser generator is the source where laser light is generated, and laser-cutting head is where the beam is transferred to material surface. Cutting head includes a nozzle, a focusing lens and a focus tracking system. The Head moves on Z-axis through NC-programming with servomotor, screw rod or a gear. (MachineMfg 2018)

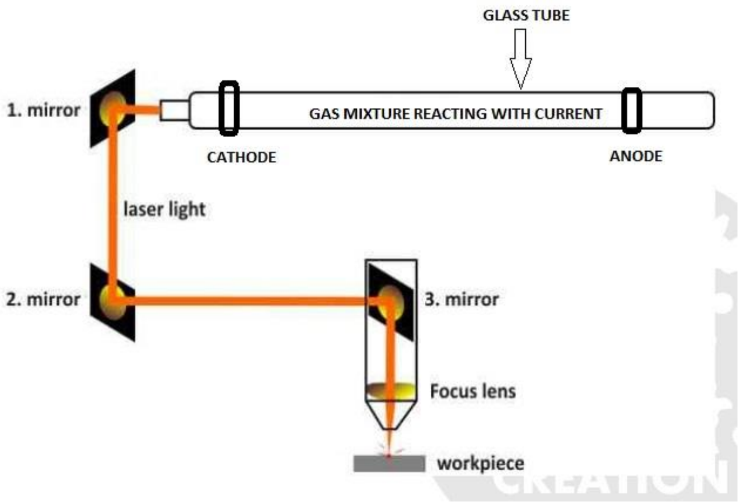
CNC-system (Computerized numerical code) controls the machines power output and cutting head´s movement on x, y and z-axis. The System is operated from operating table or platform, which is used to control cutting machine. (MachineMfg 2018)

Water chiller/unit is for cooling laser´s generator. Generator converts electrical energy into light and heat. For CO2-laser, cooling water takes heat away and cools reflector and focusing mirrors to prevent them from deformations, burns or cracks. Whereas the water unit of the fiber lasers is smaller and integrated to laser source, not needing so much space for layout planning. (MachineMfg 2018)

Gas cylinders include auxiliary gas for cutting head and other laser gasses necessary for cutting. Cutters also have their own air compressors and air-cooling dryer and filter, to provide clean dry air for laser generator and beam bath. Dust collector/extractor also cleans smoke and dust produced by the process to conform the requirements of environmental standards. (MachineMfg 2018)

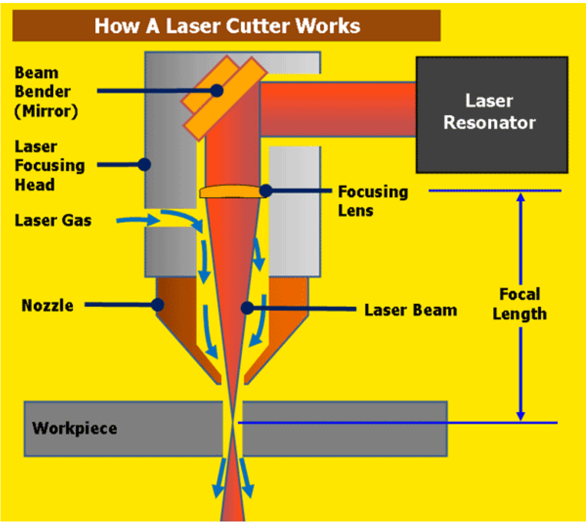
4.2 CO2 LASER

Carbon dioxide laser, also known as CO2 laser, is the most common laser cutter type in industrial usage due to its power capability and good surface quality. The beam of CO2 lasers is produced by emission, where excited atoms release photons when reaching normal status. This all happens in a glass laser tube, which has transparent mirrors at each end and resonator gas inside. Resonator gas is a mixture of carbon dioxide, helium, and nitrogen. In the glass tube there are also two electrodes, input with high voltage of direct current (2016, 11-12) according to Kauppinen. Electrodes cause the gas to radiate creating coherent light that is directed out of the tube, using beam bending mirrors and finally with focusing lens to materials surface. This creates a single pinpoint spot with a high heat density emitted in 10,6 microns wavelength. A very simple beam path example is illustrated in the picture below. CO2 lasers can have 2-10 mirrors for reflecting the beam to focus lens.



PICTURE 6. CO2 laser beam path, modified (DIY CO2 laser 2017)

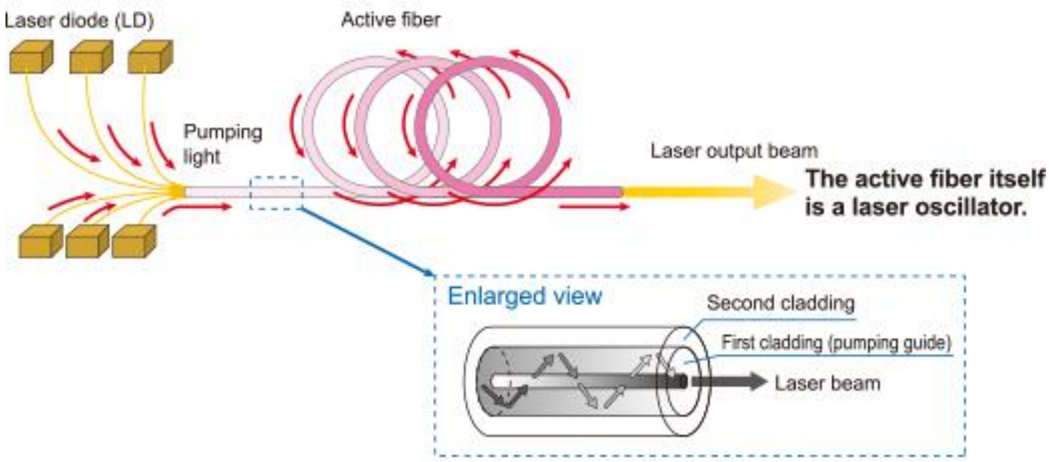
The high heat density will result in rapid heating, melting and vaporization of material. During cutting auxiliary cutting gas, either oxygen or nitrogen, is fed coaxially to surface to help in burning process, cool the materials surface and clean the molten material. In picture # laser beam is focused to work piece’s surface and cutting is in process. (Esab knowledge center 2021)



PICTURE 7. CO2 laser cutter focusing head (Esab knowledge center 2021)

4.3 FIBER LASER

Fiber laser is considered as a "new" cutting option for industrial use. It uses optical fiber to create the beam bath to cutting head. The Fiber has two layers, core- and outer layer. In the core there are earth elements. There are multiple element options, which are erbium, thulium, ytterbium, neodymium, praseodymium, holmium, or dysprosium. Erbium or ytterbium are most used due to high energy level and efficient wavelength they produce. (University of Southampton, unknown publish date). The beam is formed by stimulated emission when light is pumped by diode packs through the fiber´s inner core. Diodes transfer light to doped fiber core where part of transferring light is absorbed the ions, making them over excited. When nearing ground state ions radiate laser light and then the light is transferred to focusing lens with the fiber, so mirrors are not needed for beam transferring. Laser is emitted wavelength of 1.06 microns. Picture 8 shows the difference between CO2 laser and fiber lasers beam path before entering cutting head (Hecht 2012).



PICTURE 8. Fiber Laser energy conversion (Amada 2020).

5 COMPARISON BETWEEN FIBER AND CO2 LASER

Choosing a laser resonator type, size and power output is dependent on the application and product. The best possible options for AFT are Fiber and CO2 laser. In the comparison power consumption differences, throughput-time and accuracy difference, material options, cost differences and overall suitability for AFT are examined (Morntech 2019).

5.1 BEAM MODE DIFFERENCE

As laser uses most of the time TEM00 mode due to smallest beam waist, there can be a difference between CO2 mode and beam shape compared to Fiber-laser.

CO2 laser works always on TEM00, to achieve the best cut quality. Fiber laser can have either single mode- or multimode fiber optic cable, multimode is TEM01 as single mode is TEM00. Single Mode fiber optic cable has a small diametric core that allows only one mode of light to propagate. Multimode fiber optic cable has a large diametric core that allows multiple modes of light to propagate. (Multicom 2020). Due to larger core diameter, the quality of beam is reduced because of coarser core of the beam. Still, these should not be compared, as these are used in different applications. Single mode fiber is faster and more effective for thinner materials and multimode is faster and more effective for thicker materials. (Xtlaser 2019).

5.2 POWER CONSUMPTION, EFFICIENCY AND DENSITY

When comparing power consumption, fiber laser is much cheaper and economical option. For example, the maximum power of a 4 kW fiber cutter and chiller units can be approx. 18kW. Equal to this, 4 kW CO2 laser and chiller unit can consume 70kW of power. Power efficiency of fiber laser can be between 30-50% whereas the power efficiency of CO2 is only 10-20%. Power density for fiber-laser is much greater as well, a 2 kW fiber can have five times bigger power density on the focal point compared to 4 kW CO2 laser (Bystronic 2013). In table 1 there is an example of almost equally powerful and sized laser´s from Bystronic and power consumption of these lasers.

TABLE 1. Technical datasheet BySprint fiber and BySprint pro (Bystronic 2013).

Laser model	Cutting power (W)	Total energy consumption (kW)
BySprint Pro 3015 (CO2)	3300	40
BySprint Fiber 3015 (FIBER)	3000	21,3/22,7

5.3 THROUGHPUT-TIME AND CUTTING SPEED

Fiber laser with high power input can averagely cut five times faster than CO2 laser and Fiber-laser does not require to “warm-up” before starting whereas CO2 needs 10 minutes before cutting. Certain fiber lasers have extraordinary acceleration speed, for reference Eagle iNspire Fiber-laser has carbon fiber beam which is 2.5 times lighter than steel giving laser cornering acceleration of 6G´s. (Fairmontmachinery 2020). CO2 lasers have averagely 2G´s acceleration. Fiber laser can increase the cutting volume and decrease process time of each product cut from thin material. This makes fiber good option for bulk production where quantity is over quality. CO2 is better for slower cutting processes where quality is over quantity.

5.4 MATERIAL

Due to difference between Fiber´s 1,03-1,1 μm and CO2´s 10,6 μm wavelength, lasers cannot cut same materials. For materials thicker than 10mm, CO2 can achieve better cut quality. Fiber laser is better for reflective materials as copper, brass, and aluminum. Stainless steel and carbon steels are usually cut with CO2 laser (mcmachinery 2018).

5.5 EDGE AND SURFACE QUALITY

CO2 lasers edge- and surface quality is overall better than fiber´s, especially when accuracy is the priority. After materials thickness grows so does the difference. The reason for fiber´s lacking edge and surface quality is in focal points smaller spot size and greater assistant gas usage. When cutting thin reflective materials fiber laser cuts with better edge quality due to smaller wavelength of the beam, but when cutting stainless steel or carbon steel using nitrogen as auxiliary gas CO2 surface quality as much better.

5.6 COSTS

When comparing the purchasing cost these lasers are equal in price, but Fiber-laser is cheaper to maintain. New machines are heavily customizable with different lenses, table sizes, automation options and resonator sizes, which will increase and create more deviation in pricing. Bigger the machines power output and cutting table is, more expensive it is to buy and maintain.

CO2 laser´s main running costs come from electricity, resonator- and auxiliary gasses and wear off parts. It uses nitrogen, oxygen and helium as resonator gas and beam bending mirrors to guide the laser beam to cutting head. Nitrogen costs approx.90,5€ per gas bottle with volume of 50 liters. Same size bottle of helium costs approx.1780€ and oxygen 109,8€. These gasses can also be purchased as a mix for different laser manufacturers, price varying between 1000-3000€ per bottle (Linde-gas 2020). Wear off parts include protective lenses, nozzles, filters, connectors etc. Beam path needs maintenance work, adjustments, and new mirrors averagely 4-5 times a year. One mirror can cost 3000-3500€.

Fiber-laser running cost include electricity, auxiliary cutting gas and wear off parts. Fiber´s low electric energy consumption with better efficiency and smaller chiller unit lowers uses of electric energy and so running cost significantly. Fiber also does not require maintenance so regularly due to beam transferring with optical fiber; also, mirror expenses or resonator gas consumption do not exist. Wear off parts are same as for CO2 lasers.

In picture below is shown AFT´s current CO2 laser wear- and maintenance part costs from year 2019. If AFT decides to change from CO2 to Fiber laser, mirror costs will drop off from yearly maintenance costs, which is marked red in the picture.

WEAR PARTS	PCS	PRICE
FILTERS	16	975,35 €
FILTER CARTRIDGES	13	566,39 €
VACUUM FILTER	9	210,46 €
NOZZLES	13	268,40 €
CONNECTORS	105	746,62 €
TOTAL		2 767,21 €

MAINTENANCE PARTS	PCS	PRICE
BELLOWS	4	6 829,92 €
FREQUENCY CONV	1	620,00 €
PUMPS	5	8 023,36 €
MIRRORS	5	9 751,48 €
BOX BELLOWS	1	2 075,76 €
COMPRESSOR	1	3 694,21 €
HIG PRESS LENS	5	2 059,33 €
PHASE SHIFTER	1	808,58 €
TOTAL		33 862,64 €

PICTURE 9. AFT´s maintenance cost 2019. (Räisänen 2020)

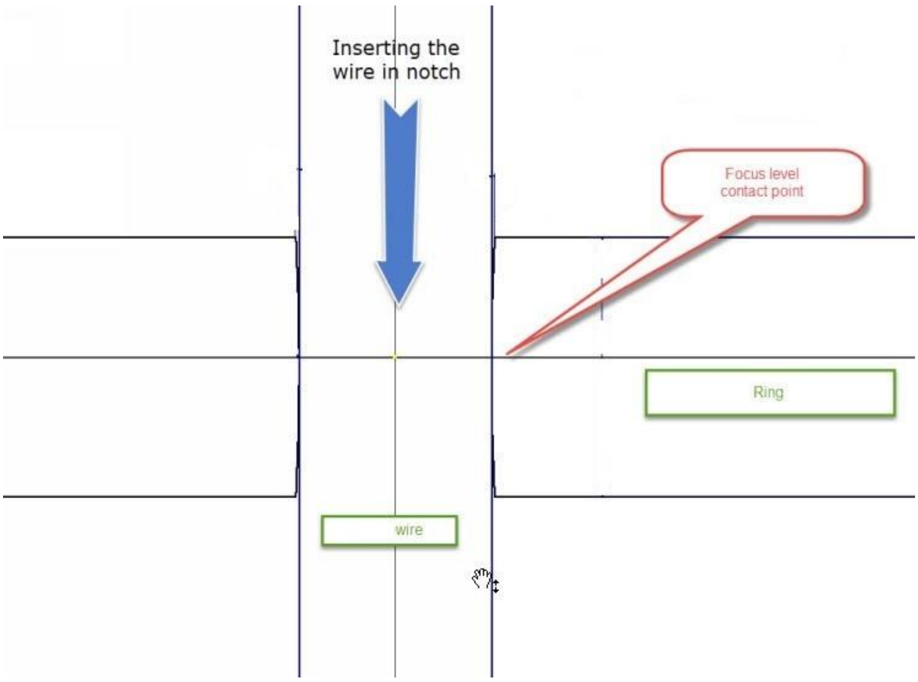
6 CHOOSING A NEW LASER-CUTTER PROJECT

AFT has decided to invest in a new laser-cutting machine to replace the old Trumpf 7040 laser. Because the investment cost is very high and production is dependent on the accuracy of the machines, it´s necessary to make a wide research of what machines are capable to fill AFT´s manufacturing- and quality needs. My part in the project includes theoretical background research of laser cutting and comparison between CO2 and fiber cutter to provide AFT background for choosing between these two resonator options. Also reporting, measuring, and calculating results of the cutting test. All this to create an official recommendation to AFT´s chain of command.

The First step of the project was deciding possible machine providers. AFT decided to select three, these providers are Amada, Bystronic and Trumpf. All the providers had in the start of the project both CO2 and Fiber-lasers in their lineup. The Second step was to start doing cutting tests with each provider.

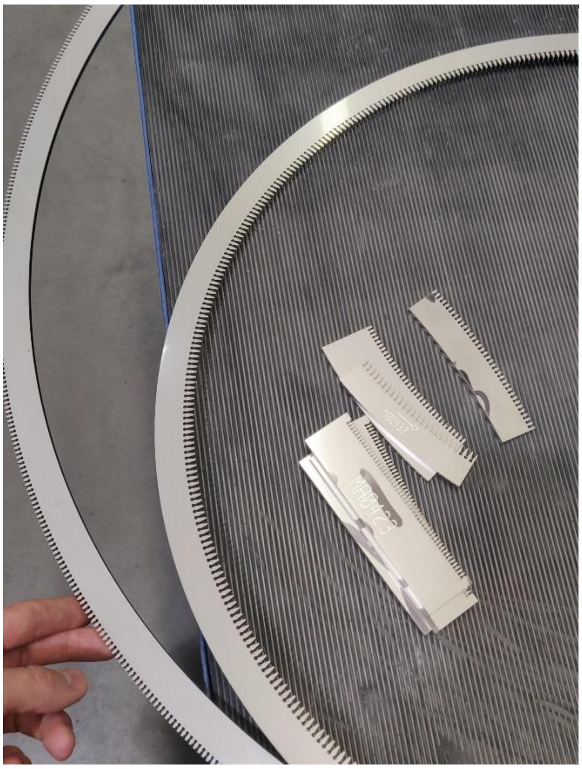
6.1 CUTTING TESTS

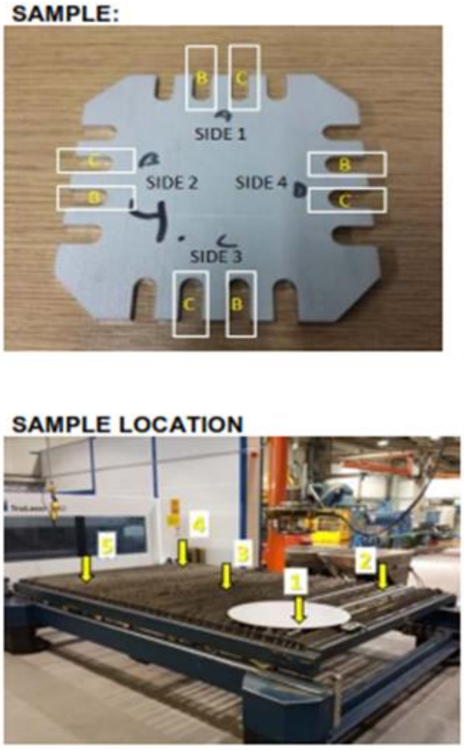
AFT´s first priorities for the cutter are good surface quality, repeatable cut and specific "hourglass" like profile as seen in the picture 7.



PICTURE 10. Needed profile shape (Vartianen 2020).

To give new providers an example of the wanted outcome, AFT provided every company already cut parts, CNC-files, and plate material. All parts were cut with 4kw power and feedrate of 2M/min. In pictures 8 and 9 it is seen support ring examples and surface tolerance test parts and notch width test parts. After providers have done their test cuts, samples will be measured and analyzed at AFT. The Measurements include visual examination, notch width measurements and profile shape checking.





PICTURES 11 & 12. Example parts that were send to providers and positioning of the parts on cutting table. (Räisänen 2020)

AFT has requirements which the new machine must fulfill. The New Laser must be optimized for MacroFlow2 production with the following target requirements (Vartiainen 2020):

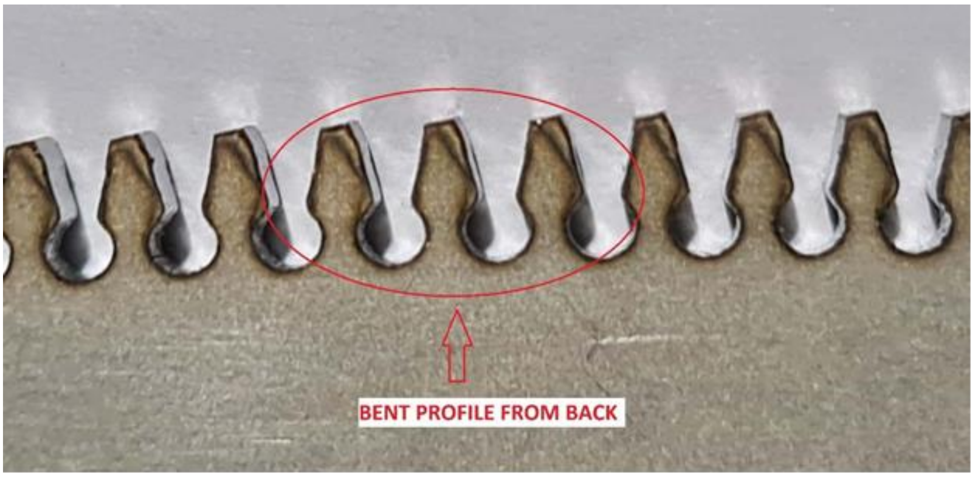
- Suitable cutting material, either EN1.14404 and EN1.4301
- Material thickness 4 and 6 mm
- Good surface quality, maximum material roughness of Ra 1,5 (same or better than test rings)
- Tight dimension tolerances. Square sample notches should have maximum of 0,02mm deviation
- KERF adjustment
- “Hourglass” shape of cut, more narrow point in middle of plate
- Cutting speed min. 2m/min average in test rings

6.1.1 BYSTRONIC TEST CUT RESULTS

Bystronic used ByStar Fiber 10kW – fiber cutter for their tests in Switzerland. This fiber laser has 10 kW power output and is designed to cut material up to 30 mm in thickness.

PICTURE 14. ByStar Fiber laser cutting machine (Bystronic 2020).

Test cuts did not have the wanted surface quality. Power output and cutting speed were too high which led to bent ligaments and burned surface.



PICTURES 15 & 16. Bystronic ring profile test cuts. (Räisänen 2020)

"Hourglass" like profile is mandatory to AFT, Bystronic could not recreate it as seen in picture 13. Bystronics surface tolerance notch width deviation was between 0,0451-0,1048 mm which is drastically larger, comparing to AFT´s need of 0,02 mm or lower.

PICTURE 17. Hourglass profile difference (Räisänen 2020)

In conclusion, Bystronics laser was optimized to cut fast and with high power, not necessary for AFT´s production. After reporting the test results to Bystronic they informed their incapability to provide laser cutter for AFT´s manufacturing needs with their Fiber-cutting options now. Bystronic has developed their fiber-cutters to cut flat and smooth profile with 1.06-micron wavelength and during the autumn 2020 Bystronic stopped the production of CO_2-lasers. Due to this, they were not able to provide a new laser to AFT.

6.1.2 AMADA TEST CUT RESULTS

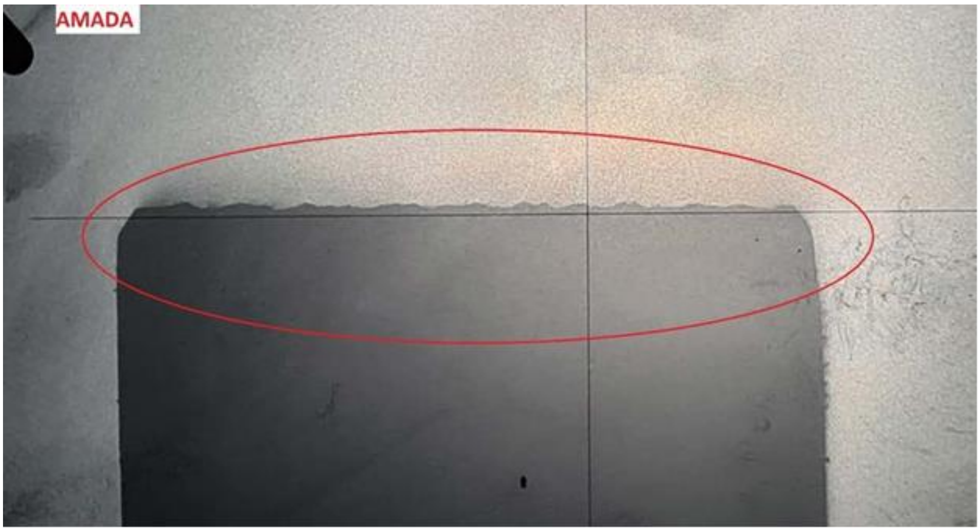
Amada used multiple machines and resonator models for test cuts to find out what is the best quality and machine they could provide. Most of the cuts were done in their demo center in United Kingdom. The First test was done with smaller cutter VENTIS 4kW Fiber-laser. After receiving the reports and feedback Amada changed their machine to ENSIS 9kW with special Silky Cut-lens option and after the third cut, Amada proposed to change resonator from Fiber to CO_2 to increase the cut´s surface quality with LC F1 3015 4kW CO_2 laser with Silky Cut lens. This showed improvement in cut results that led AFT to think maybe the CO_2 laser is still better for MF2 production. As this was going on Amada launched all new fiber cutter REGIUS AJ 6kW, which was used for cutting the latest test pats.

6.1.2.1 FIRST TEST CUTS – VENTIS 4kW

The Problems were same as with Bystronic. Cutting speed or the output power were too high leading to rough and uneven surfaces with excess slag as seen picture 14.

PICTURE 18. Amada ring sample (Räisänen 2020)

This also led into deformation on profile surface and slag forming on ligaments. Due to communication error on Amada´s part they didn´t provide square measurement samples to measure notch width deviation. In picture 15, the uneven surface of ring profile is seen.



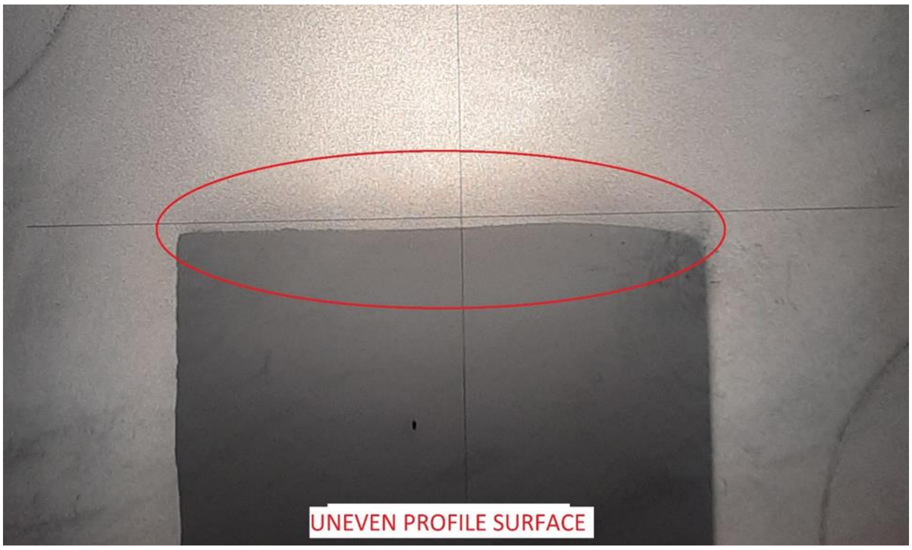
PICTURE 19. Hourglass profile surface (Räisänen 2020)

6.1.2.2 SECOND TEST CUTS – VENTIS 6kW

Amada´s surface quality improved in the second tests. Cut surface was better but had excessive slag on surface. Ligaments were bent due to incorrect cutting direction, mistake by AFT´s part, as we did not specify cutting direction.

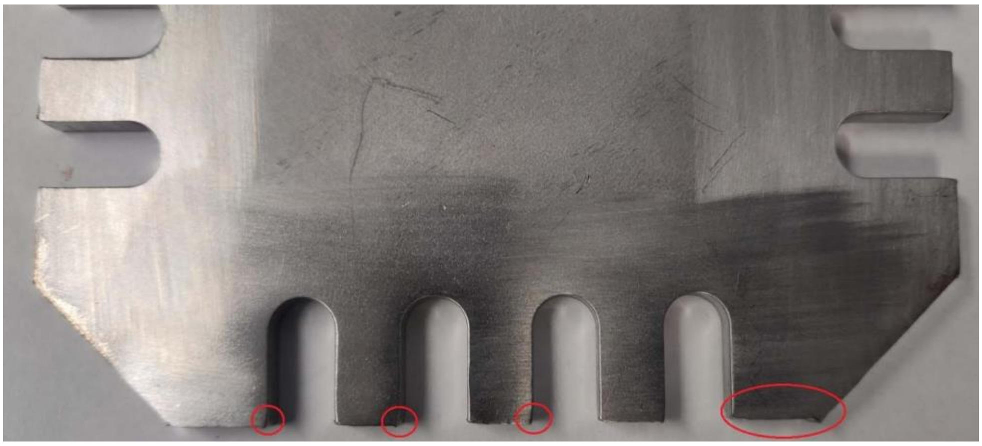
PICTURE 20. Excess slag on ring ligaments (Räisänen 2020)

"Hourglass" shaped surface was better in quality but lacked the wanted shape, turning in to more wavy than convex.



PICTURE 21. Hourglass profile (Räisänen 2020)

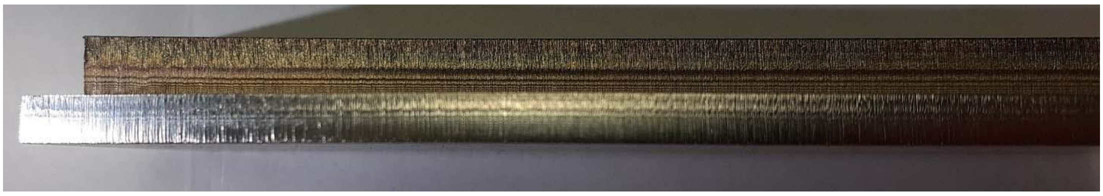
For this second test, Amada did cut surface deviation square samples. Cut quality was quite good, average deviation was measured to be 0,031 mm and lowest singular value was 0,0209 mm which would fulfill AFT´s standards. More concern was raised by the uneven cut on the sample, laser had cut corners early and interrupted the cut leaving marks on the sample surface as seen in picture 18.

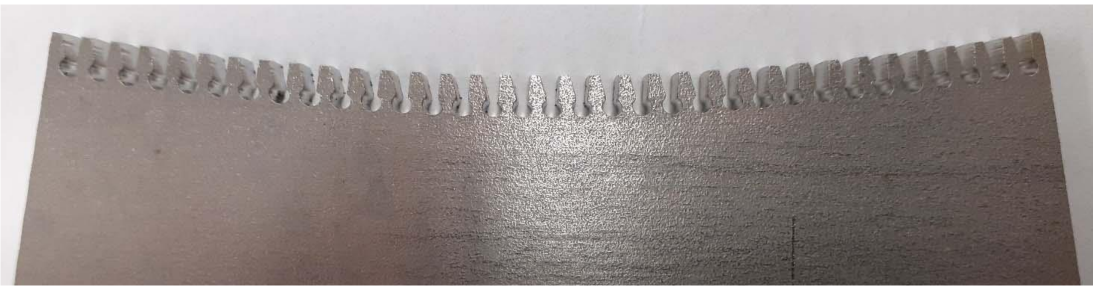


PICTURE 22. Deformed square measurement sample (Räisänen 2020)

6.1.2.3 THIRD TEST CUTS – F1 6kW

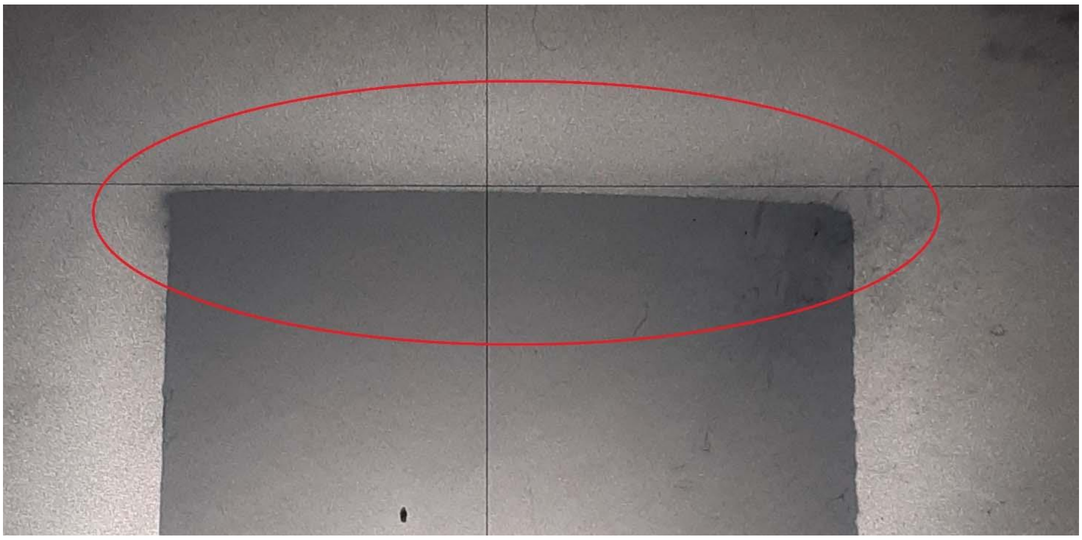
After the second test, development team had few meetings with Amada´s sales representative. Conclusion of meetings was that even promising looking fiber laser could not be optimized to AFT standards. Now for the "final" test the resonator was changed to CO2 and machine to F1 from EN-SIS. Cut quality with CO2 laser was the best so far. No excess material or slag was seen on the cut surface and deformation was minimal.





PICTURES 23 & 24. CO2 test cuts (Räisänen 2020)

Hourglass shaped ring profile was improved as well. Surface was even and nearly convex, discussion in development team led us believing that this could be corrected by changing cutting parameters in time.



PICTURE 25. Hourglass profile surface cut with CO2 (Räisänen 2020)

6.1.2.4 FOURTH TESTS- REGIUS 6kW

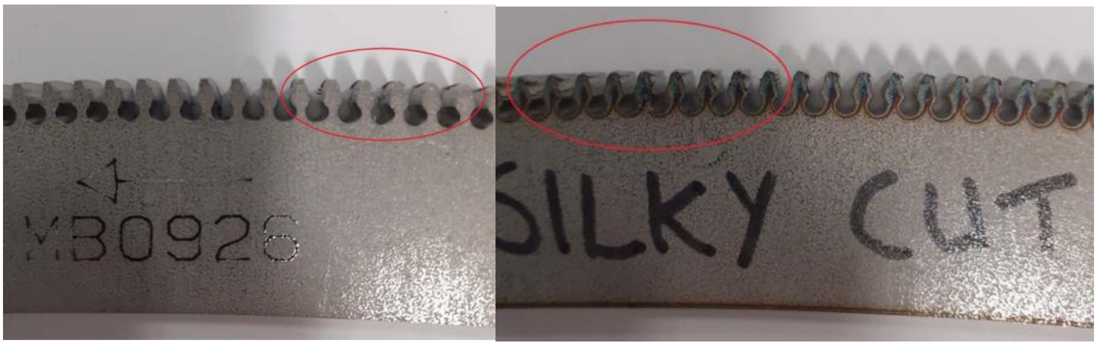
After receiving test results from parts cut with F1 Amada informed us that they will also discontinue the production of CO2 lasers after 2020 and did not have CO2 lasers anymore on European market. As earlier the test showed Amada´s incapacity to recreate the wanted quality with Fiber laser, they proposed AFT a completely new machine. Fiber laser called REGIUS, launching to European market early 2021. AFT was privileged to do test cuts with this machine in late November and early December. Amada hosted a video conference with our project team where they introduced the machine and made the test cuts. Cuts were received after Christmas due to COVID-19 lockdown in Britain.

Amada made these cuts with standard lens and silky cut lens to demonstrate the difference. Unfortunately, Amada only used 6 mm plate, which gave inaccurate information about machines real accuracy. Still ring samples surface quality was good and excess dross or slag was minimal.

PICTURE 26. Ring profile surface, standard vs silky cut (Räisänen 2020)

PICTURE 27. Ring profile, ligament gaps (Räisänen 2020)

Ligament shape was correct and hourglass profile was even to almost convex, probably can be changed to match AFT standard.



PICTURE 28. Correct ligament shape with minimal slag or dross (Räisänen 2020)

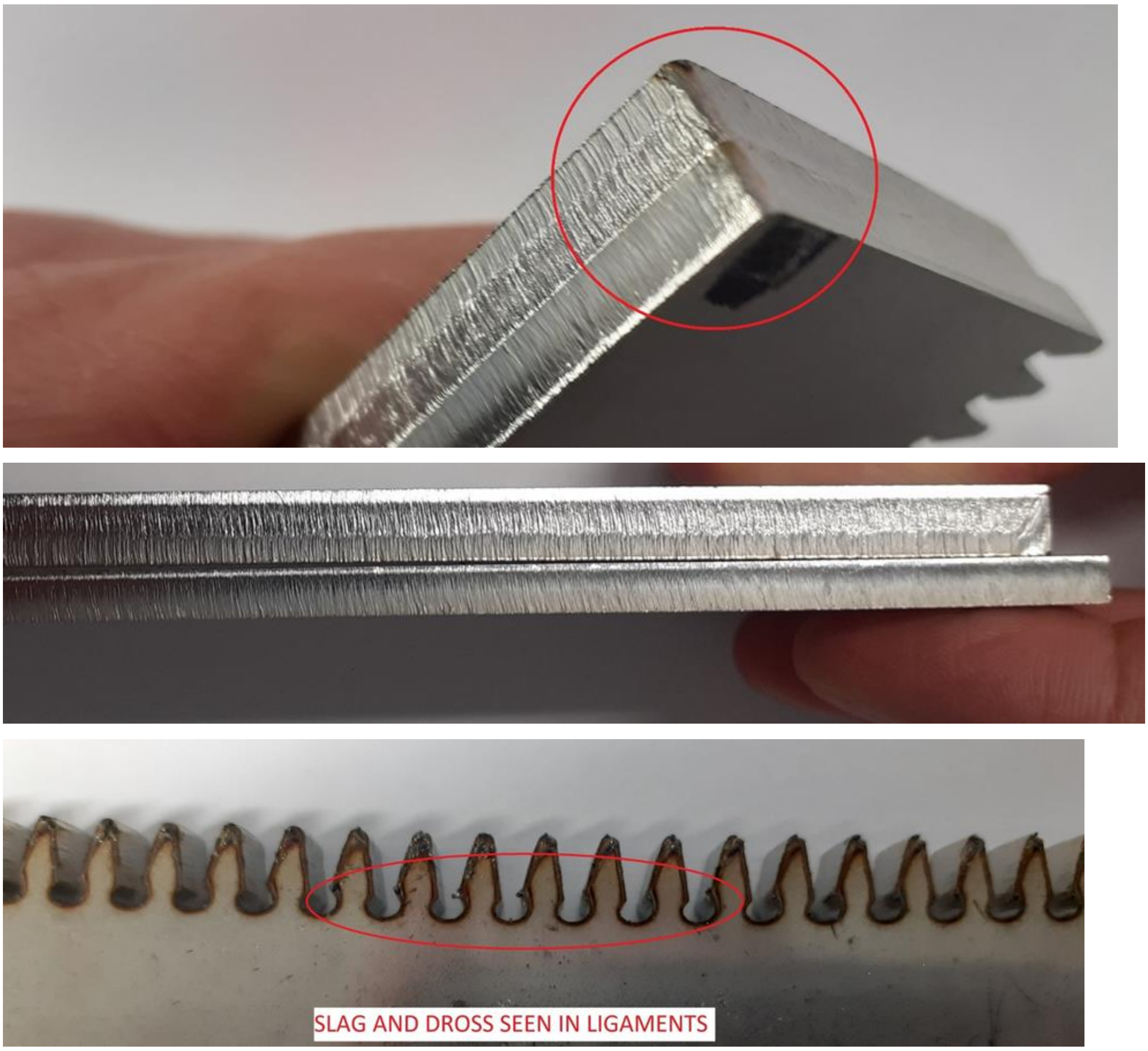
PICTURES 29 & 30. Hourglass profile, with standard and silky cut (Räisänen 2020)

Unfortunately again, Amada did not cut square measurement samples, as we sent the report, it was insisted that they would cut and send this part as well with the 4 mm plate test samples. Only with these parts, the true accuracy of the Regius cutter could be accurately measured. Amada promised to deliver these samples early 2021.

6.1.3 TRUMPF TEST CUT RESULTS

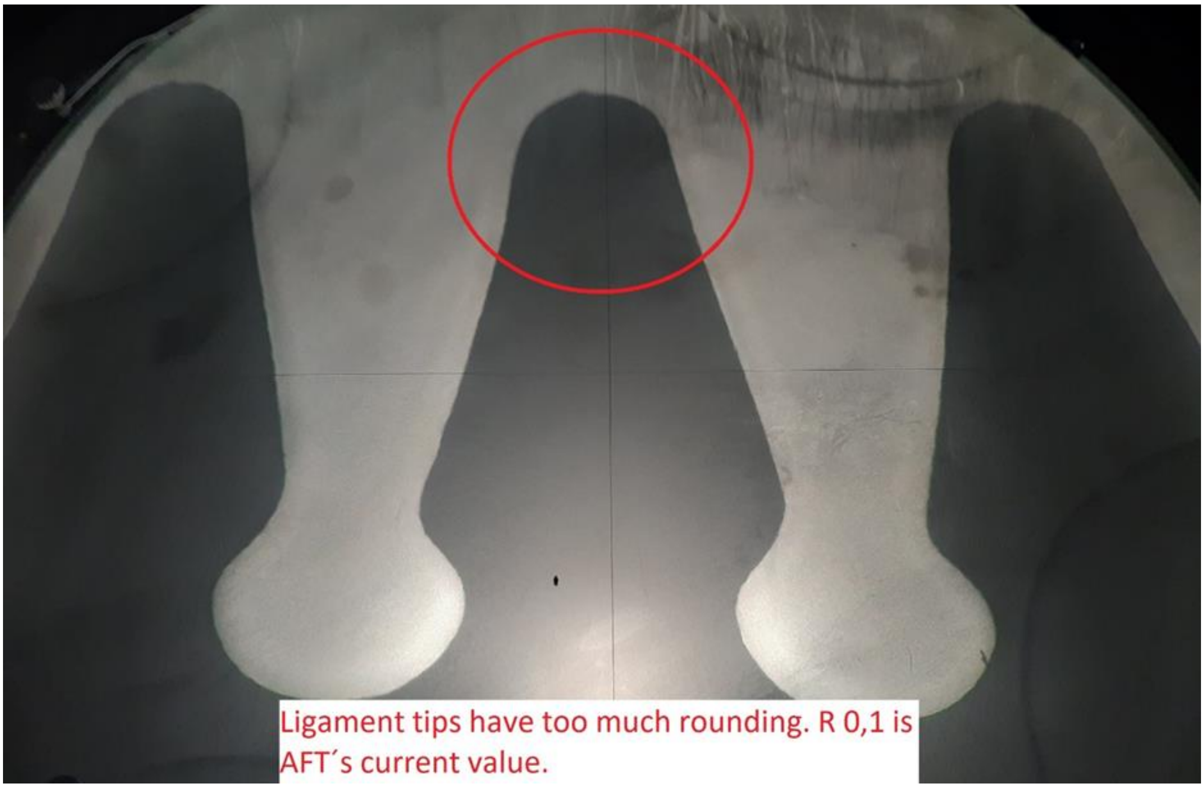
Trumpf proposed in the beginning of the year that the only machine they will recommend is the same 7040 with updated technology. As AFT trusted their experience and knowledge of our needs, this was not questioned as the old laser had created cutting quality before. The First meeting with Trumpf in early summer about test cuts timetable. It was decided to start after their holiday in late August. After not receiving any news or test results Trumpf informed AFT that they would not do any test with this machine as they can promise to provide the needed quality, announcing at the same time the discontinuation of CO2 laser technology after 2020. They set a deadline to AFT to purchase this machine before year 2021 or to change into fiber laser 5030 L76 Fiber. Test cuts were done with this 5030 fiber laser.

Surface quality was rough and burned, parts had disfiguration and cut edges and slag could be seen on the surface of ligaments.



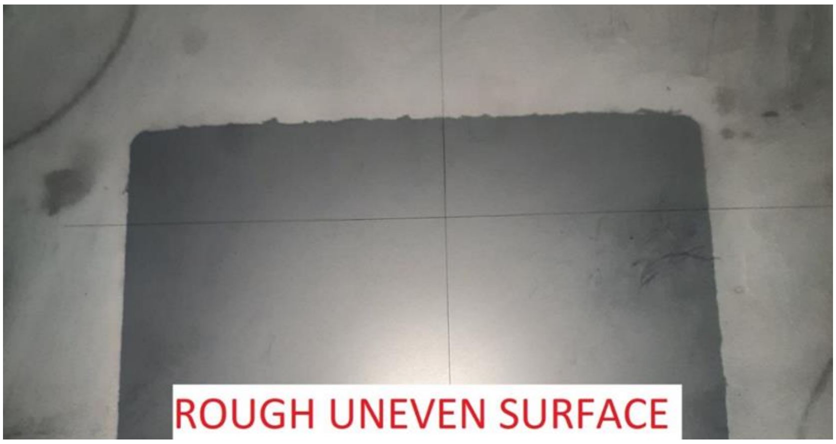
PICTURES 31, 32 & 33. Trumpf test cuts (Räisänen 2020)

Ring ligament tips were round with visual inspection and with later measurement; rounding value was set too high making ligaments disfigured. AFT´s rounding value is R 0.1.



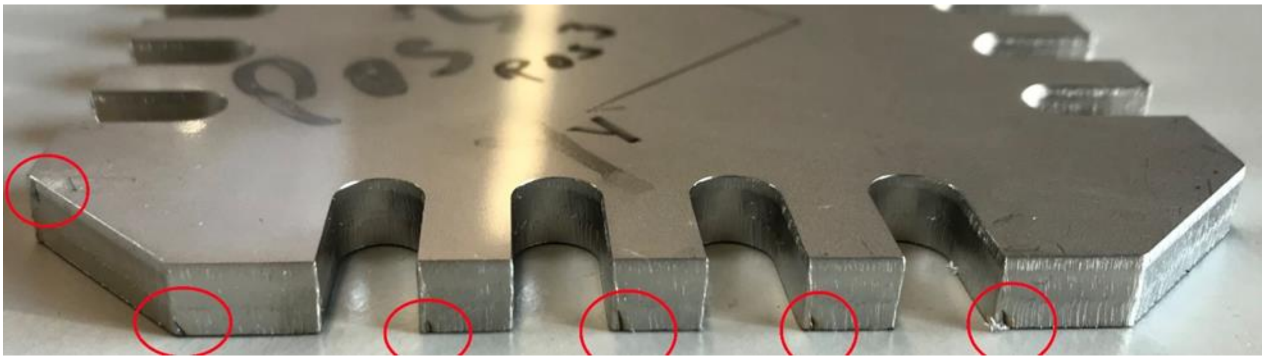
PICTURE 34. Disfigured ligament tips (Räisänen 2020)

Hourglass profile shaped surface was rough in every part we measured. In addition, the shape of hourglass profile differed from flat to convex



PICTURE 35. Hourglass shape profile (Räisänen 2020)

Surface deviation square samples also had some burn marks and cut edges. Still cut deviation was quite good, Pieces cut from 4 mm material have deviation between 0,0226-0,0476 mm, average deviation being 0,036 mm. Reason for this could be high cutting speed of 9.5 m/min, one piece took only 10 seconds to cut. Comparing these to pieces cut from 6 mm plate, deviation was better. Varying between 0,0163-0,0398 mm, and average being 0,025 mm. Now cutting speed has been 4,9 m/min and per piece cutting has taken 10 seconds. This would indicate that with lower cutting speed deviation change could be modified to get needed 0,02 mm.



PICTURE 36. Trumpf square samples burned edges (Räisänen 2020)

6.2 REPORTING

To create more understandable outcome of the test cut results, each test was reported separately and then send to providers. This allowed them to inspect the results from AFT´s viewpoint and re-adjust or change their cutting methods or machines. After final tests all the data was compiled to bigger conclusion report, which was sent to AFT´s investment project leaders and other executives for further use in the project and possibly to give a direction towards the right machine or provider.

7 CONCLUSION

As the investment project continues, the development team has reached a conclusion on which machine would be the suggestion for AFT´s future in MF2 production. If the new laser is purchased, old Trumpf 7040 will stay in Varkaus and it will be harnessed mainly for other production use that has been earlier done by subcontractors. It will also serve us as a secondary option when the new machine is down for the maintenance. (Piironen 2020)

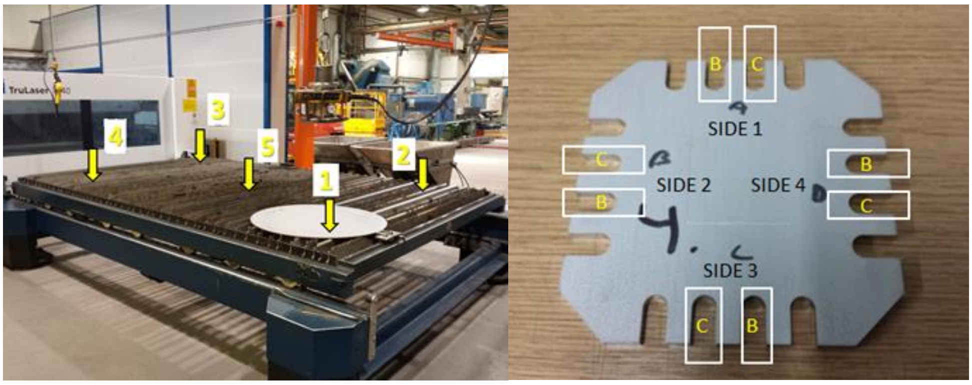
The New machine proposed to chain of command was Amada´s newest cutter, Regius, linear driven fiber laser machine with silky cut-technology. Silky cut -technology replicates the cutting quality of CO2 laser by making the beam´s spot size bigger. Samples that were cut with silky cut but with older generation machine Ventis had a surface quality close to CO2 laser. Because of linear servo movements, it is strongly believed that the accuracy of the machine will last longer for AFT´s production and will be more maintenance free as rack and pinion systems. Test cuts are still in progress, but earlier tests were promising, and Amada has been most active and responsive as company to give AFT the wanted service and quality. Regius will be released to the European market in the first quarter of 2021. (Piironen 2020)

Other options were Trumpf´s 7040 CO2 laser, which is similar machine that has been used in Varkaus for 10 years. All the movements have linear servos, like Regius. The machine had the lowest risk for production due to already known CO2 technology at AFT, but it was only available for sale at the end of 2020 without any test, which created a risk and trust issue between AFT and Trumpf. The Timetable of this big purchase was too pressing, and therefore AFT declined this option. (Piironen 2020)

Trumpf´s second proposed machine was 5030 fiber laser, similar that is used for Finebar products in Lennoxvill, Canada. After test cuts and discussion, the surface quality and accuracy of these tests were not good enough to the needs of AFT. In this model, one axis is also built with a rack and pinion system that will lose its accuracy quickly in AFT´s back and forward cut movement. Our development team continues tests to reach conclusion if this cutter is viable option for MF2 manufacturing. (Piironen 2020)

7.1 TEST CUT RESULTS

Test cuts were evaluated by visual appearance, surface roughness and notch width measurements of square samples. Parts were cut on five different places of cutting table, in all corners and one in the middle of cutting table as seen in the picture 36. The notch width was only measured from the middle notches seen in picture 38.



PICTURES 37 & 38. Square test parts (AFT 2020)

In charts, 3 and 4 is the average of maximum and minimum values of the notch width measurements and average deviation can be seen. Again, to give reference, AFT´s standard required maximum deviation of 0,02 mm. All measured parts were cut with Fiber lasers, as all CO2 lasers will be discontinued and AFT will not purchase new 7040, measurement done with CO2 laser are irrelative. All providers did cut measurement parts from 4 mm plate, but Amada did not cut 4 mm parts. As AFT primarily uses 4 mm as their ring material this affects the truthfulness of the tests.

TABLE 2. Measurements cut from 4 mm corrosion resistant stainless steel.

	Amada	Bystronic	Trumpf
Maximum (all)	-	7,147	7,081
Minimum (all)	-	7,090	7,028
Deviation (all)	-	0,047	0,036

TABLE 3. Measurements cut from 6 mm corrosion resistant stainless steel.

	Amada	Bystronic	Trumpf
Maximum (all)	7,024	7,106	7,002
Minimum (all)	6,945	6,944	6,934
Deviation (all)	0,031	0,076	0,025

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